Accepted Manuscript

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PII: S0273-2300(07)00153-5
DOI: 10.1016/j.yrtph.2007.10.005
Reference: YRTPH 2069

To appear in: *Regulatory Toxicology and Pharmacology*

Received Date: 10 April 2007
Revised Date: 1 October 2007
Accepted Date: 4 October 2007

Please cite this article as: Lee, R.J., Orden, D.R.V., Airborne Asbestos in Buildings, *Regulatory Toxicology and Pharmacology* (2007), doi: 10.1016/j.yrtph.2007.10.005

Airborne Asbestos in Buildings

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The concentration of airborne asbestos in buildings nationwide is reported in this study. A total of 3978 indoor samples from 752 buildings, representing nearly 32 man-years of sampling, have been analyzed by transmission electron microscopy. The buildings that were surveyed were the subject of litigation related to suits alleging the general building occupants were exposed to a potential health hazard as a result the presence of asbestos-containing materials (ACM). The average concentration of all airborne asbestos structures was 0.01 structures/ml (s/ml) and the average concentration of airborne asbestos ≥ 5 µm long was 0.00012 fibers/ml (f/ml). For all samples, 99.9% of the samples were < 0.01 f/ml for fibers longer than 5 µm; no building averaged above 0.004 f/ml for fibers longer than 5 µm. No asbestos was detected in 27% of the buildings and in 90% of the buildings no asbestos was detected that would have been seen optically (≥ 5 µm long, ≥ 0.25 µm wide). Background outdoor concentrations have been reported at 0.0003 f/ml ≥ 5 µm. These results indicate that in-place ACM does not result in elevated airborne asbestos in building atmospheres approaching regulatory levels and that it does not result in a significantly increased risk to building occupants.

1.0 INTRODUCTION

Beginning in the late 1970's, concerns were raised about the significance of asbestos in buildings. It was thought that the mere presence of asbestos in buildings would result in significantly elevated airborne concentrations of asbestos giving rise to measurable risks of asbestos disease to building occupants and maintenance workers. At that time there was little data available on which to evaluate these concerns. Since then there have been a number of evaluations of asbestos concentrations in indoor air. This paper summarizes the largest set of indoor ambient air measurements ever published.

Asbestos has been used in a variety of building materials and, before abatement programs, could be found in most buildings constructed prior to 1975. Renovation and asbestos abatement have removed asbestos-containing-materials (ACM) from a large number of buildings. Building owners/operators have used the court system to seek recovery of the associated costs for the removal of ACM. Their suits claim that occupants of the buildings are potentially exposed to hazardous airborne levels of asbestos resulting from spontaneous emission of asbestos fibers from in-place building products or disturbance of the products during routine housekeeping, maintenance or renovation. They further claim that a responsible party such as the manufacturer of the product, the builder, and/or the architect should compensate the owner for recommending, selling or installing a defective or unsafe product.

In response to the claims, and because of the lack of a robust data set reflecting the concentrations of asbestos in indoor air, a number of defendants and building owners sponsored testing of the air in buildings. The goal was to establish airborne concentrations of asbestos in buildings under conditions of normal occupancy. Portions of the data reported herein have been reported previously (Corn *et al.*, 1991; Lee *et al.*, 1992). Other groups have also reported airborne asbestos concentrations from buildings (HEI-AR, 1991; WHO, 1986). With the exception of the WHO study, the average airborne concentration for fibers ≥ 5 µm in past studies were all less than 0.001 f/ml. Comparisons of these data to historical exposures of workers in the asbestos products industry can be used to estimate the level of risk to the occupant (Hughes *et al.,* 1987; Mossman *et al.,* 1990).

The number of samples and the number of buildings tested have roughly doubled since our last paper (Lee *et al.*, 1992). The updated data is reported herein and used to evaluate various postulated risk factors.

2.0 SOURCES OF DATA

The procedures and methods used on the samples have been described in detail in earlier reports (Lee *et al.*, 1992) and will be summarized here.

The air samples described in this report were collected in buildings in which asbestos removal was alleged to be necessary because of the risk to occupant health. Buildings were not sampled if removal activities had already been carried out or if defendants were denied access to the buildings. Also, some buildings were not sampled because of time or cost constraints. Typically, a number of samples were collected outdoors and from indoor areas representing different activity levels, and from these, five indoor or personal, two outdoor, and one blank sample were analyzed from each building. The samples from 752 different buildings nationwide were collected over a 10-year period and represent all of those analyzed by RJ Lee Group for defendants in asbestos in buildings litigation.

2.1 Building Survey

Indoor and utdoor air sampling as well as building surveys to verify the presence of ACM were performed by a team composed of a certified industrial hygienist, who acted as team leader, and three or more assistants. The actual sampling sites within the recommended buildings were selected by the survey teams on-site on the basis of location, use and other factors described below. All buildings were classified as schools (both public and private elementary and secondary education buildings), universities (post secondary educational buildings), commercial buildings (buildings generally limited to business or for-profit activities), or public buildings (hospitals, libraries, governmental offices, etc.). A small number of residences were sampled.

2.2 Air Sampling

Air sampling was conducted to determine the airborne fiber concentrations in occupied buildings. Sampling was conducted both in areas where ACM was present and in areas (if any) where ACM was absent. The survey teams noted whether the occupancy levels were high, medium or low. These ratings were subjective in nature and depended upon actual usage at the time of the survey. Sampling was also conducted outside the buildings to allow comparison between outdoor and indoor fiber levels.

Air sampling equipment adhered to the requirements of the National Institute of Occupational Safety and Health (NIOSH) Method 7400 (NIOSH, 1994) and the Asbestos Hazard Emergency Response Act (AHERA) (USEPA, 1987). Normally pumps were operated at a flow rate of 2 to 3 liters per minute. Each sample volume was kept within the range of 600 to 2500 liters with a target of about 2000 liters. Sampling at each building was conducted over a 2-day period and during normal building use to obtain representative conditions. The samples were collected on two types of filters, cellulose ester membrane (both 0.8 and 0.45 µm pore size, 25-mm diameter) and polycarbonate filters (0.4 µm pore size, backed with a 5 µm cellulose ester filter). Each filter was mounted in a new cassette with a 2-in. conductive extension.

2.3 Sample Analytical Procedures

The measurement of asbestos concentration from samples by transmission electron microscopy (TEM) consists of sample preparation, asbestos fiber identification, reporting and quality assurance. Techniques for each of these phases have been developed by a number of groups over a period of years. The methods used closely parallel those of Lee *et al.* (1977), Yamate *et al.* (1984), and AHERA (USEPA, 1987).

The laboratory chose the samples that were analyzed from the collected sets. Typically, one outdoor sample and five indoor samples were chosen from each building.

Samples that were selected were randomly chosen based on location and volume sampled (at least 1000 liters or about 500 min of sample time).

Prepared samples were analyzed using a TEM equipped with an energy dispersive X-ray detector mounted on the TEM column. The equipment was aligned, calibrated and maintained in accordance with required quality assurance standards.

Following the qualification of the grids, random grid openings (usually 10) were selected equally from two grids and systematically scanned at magnifications of 15,000 to 20,000 with overlapping traverses of the open area. Structures with an aspect ratio of ≥ 3 to 1 (length to width) were identified morphologically. Bundles, clusters, and matrices were classified according to the USEPA Level II (Yamate *et al.*, 1984) protocol. The number, length, width and mineral type meeting this aspect ratio were recorded. Particles were classified as chrysotile, amphibole or nonasbestos following the definitions developed by Yamate (Yamate *et al.*, 1984). A combination of morphology, energy dispersive X-ray analysis and selected area electron diffraction (SAED) were used in making the identifications.

2.4 Statistical Analysis

For each individual sample the total structures per unit air volume (s/ml) was calculated along with the concentration for fibers ≥ 5 µm (f/ml) and the concentration for structures with lengths ≥ 5 µm and widths of at least 0.25 µm. The last category is referred to as "optically equivalent" fibers and represents the fraction of fibers that would be identified by phase contrast microscopy. The concentration of optically equivalent fibers is used to calculate risk in accordance with the EPA IRIS model (USEPA, 1988b). In addition to structure concentration, mass concentration (ng/m^3) was also determined based on the number and size of identified structures. For data evaluation purposes, all samples with no asbestos structures counted were treated as 0 s/ml and not as "less than" a detection limit (Oehlert *et al.*, 1995).

A recently proposed risk analysis procedure (Berman and Crump, 2003) bases lung cancer risks on the concentration of fibers thinner than 0.4 µm and longer than 10 µm. An earlier version of the procedure (Berman and Crump 1999) counted fibers thinner than 0.5 µm and longer than 5 µm. The data in this study were sorted into the concentrations for fibers thinner than 0.5 µm with lengths 5-10 µm or >10 µm.

Air concentrations calculated from indoor stationary samples were averaged for each building. Summary averages and percentiles of building averages are presented by building type (school, university, commercial, public, and residential). Averages and percentiles of outdoor samples and personal samples are based on individual samples rather than building averages.

Standard statistical procedures were used in evaluating the data. Because most parametric statistical approaches, which are based on normality assumptions, are apt to give poor approximations to significance levels because asbestos sample data are generally highly skewed, nonparametric test were also used in evaluating the data. The parametric tests included analysis of variance (ANOVA), among others. The Kruskal-Wallis test (Feldman *et al.*, 1987), a nonparametric procedure, was used to test for differences among indoor concentrations among different building types. These tests have been used previously with asbestos sampling data (Chesson *et al.*, 1990; Crump *et al.*, 1989).

3.0 RESULTS OF THIS STUDY

A total of 6566 air samples from 752 buildings are reported in this study, including 1615 indoor samples from 317 schools, 989 indoor samples from 196 university buildings, 1335 indoor samples from 234 public and commercial buildings, and 39 indoor samples from residences. There are a total of 3978 indoor samples (exclusive of personal samples), 1678 outdoor samples, 111 personal samples, and 799 blanks. Approximately half of these data have been reported earlier (Lee *et al.*, 1992).

The average analytical sensitivity was 0.00302 ± 0.00006 s/ml for the 3978 indoor samples. This value varied based upon the amount of air sampled and the number of grid openings counted.

The average concentration of asbestos structures for all indoor samples was 0.01345 s/ml (Table 1); for asbestos structures ≥ 5 µm, the sample concentration averaged 0.00012 f/ml. The corresponding values for the outdoor samples were 0.00109 s/ml and 0.00003 f/ml, respectively. Table 1 lists the results for several categories of buildings and sample types. The distribution of building concentrations for fibers of all sizes is shown in Figure 1. Of all buildings, 27% contained no airborne asbestos and 86% contained no airborne asbestos ≥ 5 µm long. In 64% of the indoor samples, no asbestos was detected while in 97% of the samples, no fibers ≥ 5 μm long were detected.

Table 2 shows the average concentration of optically equivalent fibers to be 0.00008 f/ml for indoor samples and 0.00004 f/ml for outdoor samples. The weighted ratio (by number of buildings) for indoor samples of the average asbestos mass concentration (ng/m^3, a measure of airborne asbestos commonly reported before the early 1980's) to the average asbestos number concentration (s/ml) is 202 (ng/m^3)/(s/ml). Of all buildings, 90% contained no optically equivalent fibers while 98% of the indoor samples showed no optically equivalent fibers. The concentration of fibers longer than 5 μm and thinner than 0.5 μm are very similar to the optically equivalent fibers.

There are significant differences in concentration between schools, universities, and public/commercial buildings for asbestos structures of all sizes ($p < 0.0001$) with the school concentrations significantly higher than in the other buildings; there were no statistical differences between university and public/commercial buildings. There appear to be marginal differences in the concentration of fibers ≥ 5 μm (ANOVA $p = 0.0537$, Kruskal-Wallis $p = 0.0020$) and for optically equivalent fibers (ANOVA $p = 0.1041$, Kruskal-Wallis $p = 0.0176$) among these buildings with schools having higher concentrations than the other building types. There were no significant differences between the buildings types when Berman-Crump fiber concentrations were evaluated (ANOVA $p = 0.22$, Kruskal-Wallis $p = 0.0666$), though there are indications schools have higher concentrations than the other buildings.

Significant differences were observed between indoor and outdoor samples for asbestos structures of all sizes ($p < 0.0001$ for all building types) with indoor concentrations higher than those observed outdoors. For fibers ≥ 5 μm, there are significant differences between indoor and outdoor samples for schools ($p < 0.0001$) and public/commercial buildings ($p = 0.0423$); significant differences for university buildings are observed only when comparing logarithms of the concentrations ($p = 0.0171$ transformed, $p = 0.0507$ non-transformed). For fibers ≥ 5 μm, the indoor air concentrations were greater than those observed outdoors.

Table 3 summarizes the median, 90th percentile, and maximum average building concentration information for each building type. In addition, the mean and maximum values observed on individual samples within a building type are also shown in Table 3. In school buildings, 90 percent of the buildings contained total asbestos concentrations less than 0.05 s/ml. Similarly, 90 percent of the school buildings had concentrations of asbestos ≥ 5 μm less than 0.00060 f/ml. The majority of buildings (of any type) showed no fibers longer than 5 μm.

There are significant differences between building types when considering the outdoor samples collected for each building ($p = 0.0250$). The average asbestos s/ml values are: school outdoor, 0.00153 s/ml; university outdoor, 0.00110 s/ml, and public/commercial outdoor, 0.00055 s/ml. The sampling data do not provide any information to explain these differences. There are no statistically significant differences between building types for asbestos ≥ 5 μm ($p = 0.6$).

Table 4 shows the length and width distribution for chrysotile and amphibole structures. Most of the chrysotile are very thin (97% less than 0.2 µm in width) and short (83% less than 1 µm long). Only 2.7% of the fibers were amphiboles. The amphiboles were longer (only 31% less than 1 µm long) and thicker (only 41% less than 0.2 µm in width) than the chrysotile asbestos observed in these studies. Only 8% of the building samples contained any amphibole structures, and of those, 85% contained a single amphibole structure. The majority of the amphibole particles were identified as actinolite (75%), with the rest amosite (24%) or tremolite (1%). Anthophyllite and crocidolite were not detected in these samples.

4.0 DISCUSSION

Asbestos-containing materials (ACM) were installed in buildings throughout the US for more than 60 years. ACM usage dramatically increased with the advent of spray-on surfacing materials and the corresponding increase in high-rise buildings in the early 1960's. Estimates were that at least 733,000 public and commercial buildings had asbestos-containing surfacing materials, there were possibly many more (Strenio, 1984). Discovery of asbestos disease among asbestos insulators in the 1960's prompted concerns about the potential for disease in other populations and led to restrictions on asbestos usage in the early 1970's.

In the late 1970's, work by Sawyer (Sawyer, 1977) prompted widespread concern about the potential implications of asbestos surfacing materials in buildings. Sawyer found asbestos debris in the Yale Law Library and measured elevated fiber concentrations by

PCM. Sawyer postulated a pathway model for exposure that included spontaneous release of fibers from in-place materials and episodic exposures through entrainment of fibers from asbestos dust and debris as primary pathways or exposure routes for asbestos exposure to building occupants.

Inspired by Sawyer's model, it was postulated in the late 1970's that the mere presence of asbestos-containing surfacing materials in buildings would cause a second wave of asbestos disease, particularly mesothelioma, in the general population. More than 30 years have elapsed since the formulation of those postulates. However, no scientific data emerged to support them and by the early 1990's the EPA published its "Green Book" (USEPA, 1990), stating that "the health risk to most building occupants … appears to be very low".

Additional studies have been published documenting airborne asbestos concentrations in buildings similar to ambient air concentrations. Based on an extensive evaluation of 49 public buildings in five cities, the EPA, in a 1987 report to Congress, concluded that airborne asbestos levels in public buildings with asbestos-containing surfacing materials were no different than outdoor air (USEPA 1988a). Other studies have been published in peer-reviewed literature with substantially the same conclusions (Chatfield 1985, Burdett 1987, Corn 1991, Lee 1992, Camponiano 2004). These studies generally show indoor air levels are not significantly different than outdoor air levels and that maintenance worker exposures are generally well below regulatory levels. The effect of random fiber release episodes, whether from repair/maintenance activities or from "falling or dislodging" of ACM, do not substantially increase average building concentrations (Price 1992). In addition, neither the condition of in-place ACM nor the accessibility of ACM is correlated with airborne asbestos concentrations (Corn 1991).

By 1990, EPA had altered its guidance on asbestos to recommend that in-place ACM in good condition be managed in place. As noted by the EPA, "[b]ased upon available data, the average airborne asbestos levels in buildings seem to be very low. Accordingly, the health risk to most building occupants also appears to be very low" (EPA 1990). In 1992, a study conducted by the Health Effects Institute-Asbestos Research Panel (HEI-AR 1992), under a mandate from Congress, concluded that airborne levels in well-maintained buildings with asbestos-containing surfacing materials were no different than ambient background levels.

Various airborne concentration targets have been used to determine acceptable levels for re-occupancy following a clean-up or as a screening level (CPOC 2003, USEPA 2003, USEPA 2005). Had these values been regulatory levels, then 2% of the buildings would have exceeded the Hurricane Katrina level of 0.01 f/cc (USEPA 2005), 50% would have exceed the EPA Libby clean-up criteria (0.001 s/cc, USEPA 2003) and 35% would have exceeded the clean-up criteria for World Trade Center particles (0.022 s/cc, CPOC 2003).

Risk estimates for building occupants exposed to airborne asbestos, calculated from this data set, show no measurable increase in risk from prior estimates. Risk estimation assumes the buildings sampled in this data set are representative of buildings nationwide and that historical occupational exposure data (used to create the risk models) can be extrapolated to these much lower concentrations. The IRIS risk model suggests that optical microscopy of asbestos fibers counts fibers longer than 5 µm and wider than 0.4 µm, but the analytical procedure (NIOSH 1994), indicates the observable width of asbestos fibers is 0.25 µm. The effect of including these thinner fibers is to slightly increase the risk estimates. The inclusion of these additional fibers has been used by other investigators (Weiss 2001, Lioy 2002).

Under such conditions, the asbestos cancer risk to building occupants is 2.1 per million for people working in schools to 1.1 per million for people working in public/commercial buildings. HEI-AR (HEI-AR 1992) calculated similar levels of risk for building occupants. For comparison, workers exposed to the current OSHA permissible exposure limit of 0.1 f/cm^3 have a risk of 2 per 1000 or 2000 per million. Thus, building occupants have risk levels 1000 times lower than presently permitted by OSHA. By contrast, persons solely exposed to background levels of airborne asbestos (as measured here by the outdoor air samples) would have risks of 0.4 per million. Though the risks associated with building exposures are higher, they are not significant increases.

The samples reported in this study, together with numerous other studies and the results of investigations into the significance of asbestos-containing surfacing materials in buildings, lead to the following conclusions:

In-place asbestos-containing surfacing materials do not spontaneously release or shed respirable asbestos fibers nor, under conditions of normal usage, result in elevated airborne asbestos levels in buildings. No attempt was made in this paper to determine if airborne asbestos levels were correlated with various possible determinants of airborne asbestos levels, such as type and condition of ACM or type of airflow. However, no such correlations were found in an earlier report (Corn *et al*., 1991) of a subset of data from schools. The average concentrations are somewhat lower than previously reported (Lee *et al*., 1992), possibly due to a combination of factors, such as operation and maintenance activities in the later buildings, the ACM may have been in better condition in the latter buildings (regardless of O&M activities), or it may simply reflect improved statistics due to additional data.

Overall, the data presented in this report and in the HEI and WHO reports all present a consistent picture of uniformly low airborne asbestos concentrations in buildings. This finding is consistent with a recent report of airborne asbestos in Italian schools (Camponiano, 2004) which reported a maximum concentration of 0.0022 f/mL. The data reported herein indicate that average asbestos concentrations in buildings with ACM are far below (typically on the order of 1000-fold) federal action levels. It is important to note, however, that the action levels themselves are considerably below any levels shown to cause disease in humans (USEPA 1986, WHO 1998, IOM 2006). Further, the data indicate that many of the indoor locations sampled have airborne fiber concentrations that are below the 0.1 s/ml USEPA clearance level.

The asbestos structures found in building air are much smaller than those found in occupational settings. The percentage of chrysotile longer than 10 µm was 0.38%. This is 10 to 40 times less than that observed by Dement and Harris (1979) for textile manufacturing.

For equivalent work histories, the expected lifetime exposure (i.e., concentration, frequency and duration of exposure) associated with airborne asbestos levels in buildings is only a small fraction of the projected lifetime exposure contemplated by the OSHA PEL concentration of 0.1 f/cc on an 8-hour Time Weighted Average (TWA). Each sample in this study represents approximately 2 days of sample collection (or about 7900 – 8000 total days). This is equivalent to approximately 32 man-years of sampling. Of the 3978 indoor building samples collected, no sample exceeded 0.1 f/ml (fibers ≥. 5 µm) and only 3 samples (from different buildings, representing a physics room, a hallway, and a mechanical room) exceeded 0.01 f/ml. Thus, in at most 6 days out of nearly 32 years of sampling do the asbestos concentrations approach the OSHA limit of 0.1 f/ml.

The data reported herein may be used to estimate the magnitude of risk as related to various measures of concentration. The US EPA uses the IRIS model (US EPA, 1988b) to calculate risk based on the concentration of optically equivalent fibers (usually described as 5 µm and longer, a minimum width of 0.25 µm, and a minimum aspect ratio of 3:1). Weis (Weis, 2001) used this model and fiber definition to calculate risk estimates for residents of Libby, MT, adjusting the model for the duration of exposure. Lioy (Lioy 2002) conducted a similar calculation for residence of Sparta, NJ who lived near a marble quarry. Assuming IRIS is appropriate for a low dose exposure, risk estimates for this study were determined to range from 2.1 per million for people working in schools to 1.1 per million for people working in public/commercial buildings.

Berman and Crump (Berman, 2003) have proposed using different fiber dimensions for estimating concentrations used to calculate risk estimates. Their model suggests that the concentrations of long, thin fibers (fibers longer than 10 µm and thinner than 0.4 µm) are most closely correlated to cancer risk. The average concentrations for these structures can be estimated from the data in Table 2. Using the Berman-Crump model, the average risk for building occupants (male, non-smokers) ranges from 2.34 per million to 3.3 per million, similar to the estimates calculated using the IRIS model.

The Berman-Crump model is recognized though there is still some controversy about the significance of short versus long fibers. More recent work (Kuempel et al 2006), however, points to long fibers as being most important when relating fiber dimension and cancer risk. Two recent publications (Suzuki et al 2005 and Dodson and Hammer, 2006) indicate that, for mesothelioma, a preponderance of short fibers is found in tissue samples. The findings of short fibers are indicative of an exposure to airborne asbestos, but are not necessarily indicative of the causation of disease. An expert panel (ERG 2003) recently concluded that asbestos fibers "shorter than 5 µm are unlikely to cause cancer in humans"; they concluded the phrase "reasonable certainty of no harm" best described fibers shorter than 5 µm.

These risk estimates, combined with the low observed concentrations, indicate that in-place ACM does not result in elevated airborne asbestos in building atmospheres approaching regulatory levels and that in-place ACM does not result in a significantly increased risk to building occupants..

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Figure Caption

Figure 1. Percentile distribution of building averages for all asbestos structures (s/ml).

TABLE 1

SUMMARY OF BUILDINGS SAMPLED AND MEAN ASBESTOS-IN-AIR CONCENTRATIONS FOR ALL ASBESTOS STRUCTURES, AHERA STRUCTURES, AND MASS CONCENTRATION

			Structures/ml		AHERA[a] (s/ml)		All structures (ng/m^3)	
Building Type	No. Buildings	No. Samples	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
All	752	3979	0.01344	0.06787	0.00641	0.02903	2.82	18.68
P&C [b]	234	1336	0.00211	0.00421	0.00128	0.00228	3.66	29.92
Public [c]	114	590	0.00232	0.00468	0.00131	0.00218	4.91	40.43
Commercial [c]	120	746	0.00190	0.00371	0.00126	0.00239	2.47	14.07
Residential [c]	5	39	0.00273	0.00240	0.00176	0.00197	0.39	0.40
School [c]	317	1615	0.02735	0.10240	0.01265	0.04364	3.36	12.46
University [c]	196	989	0.00476	0.01326	0.00256	0.00662	1.01	4.32
Outdoor [d]		1678	0.00109	0.00634	0.00074	0.00475	0.79	15.55
Personal [d]		111	0.01642	0.06415	0.01266	0.06287	4.39	37.01

[a] Asbestos having a length of at least 0.5 µm and at least 5 times the width (used in AHERA regulations to define when schools are sufficiently free of asbestos following abatement).

[b] Combined Public and Commercial buildings. Average of building averages.

[c] Average of building averages.

[d] Average of individual samples.

TABLE 2

SUMMARY OF BUILDINGS SAMPLED AND MEAN ASBESTOS-IN-AIR CONCENTRATIONS FOR VARIOUS MEASURES OF ASBESTOS FIBERS LONGER THAN 5 μM

			Fibers (≥5 μm)/ml		Optical Equivalent[a] (f/ml)		Length ≥ 5 μm Width < 0.5 μm (f/ml)		Length ≥ 10 μm Width < 0.5 μm (f/ml)	
Building Type	No. Buildings	No. Samples	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
All	752	3979	0.00012	0.00037	0.00008	0.00029	0.00007	0.00026	0.00002	0.00012
P&C [b]	234	1336	0.00009	0.00034	0.00006	0.00025	0.00005	0.00026	0.00002	0.00010
Public [c]	114	590	0.00007	0.00021	0.00004	0.00014	0.00005	0.00019	0.00001	0.00007
Commercial [c]	120	746	0.00012	0.00043	0.00007	0.00032	0.00006	0.00031	0.00002	0.00012
Residential [c]	5	39	0.00005	0.00012	0.00005	0.00012	0	0	0	0
School [c]	317	1615	0.00016	0.00039	0.00011	0.00030	0.00009	0.00027	0.00002	0.00012
University [c]	196	989	0.00009	0.00037	0.00006	0.00030	0.00005	0.00026	0.00002	0.00014
Outdoor [d]		1678	0.00003	0.00033	0.00002	0.00025	0.00002	0.00028	<0.00001	0.00013
Personal [d]		111	0.00134	0.01189	0.00036	0.00300	0.00100	0.00894	0.00003	0.00031

[a] Fibers at least 5 μm long and with a width of at least 0.25 μm (fibers projected to be counted by phase contrast microscopy).

[b] Combined Public and Commercial buildings. Average of building averages.

[c] Average of building averages.

[d] Average of individual samples.

TABLE 3

PERCENTILE CONCENTRATIONS OF ASBESTOS-IN-AIR FOR SELECTED SAMPLE SETS

Building Type	Structures/ml	Fibers (≥5 µm)/ml	ng/m^3	AHERA [a] (s/ml)	Optical [b] (f/ml)
			Median Building Average		
All	0.00149	0.00000	0.032	0.00105	0.00000
P&C [c]	0.00059	0.00000	0.006	0.00053	0.00000
Public [d]	0.00055	0.00000	0.002	0.00050	0.00000
Commercial [d]	0.00072	0.00000	0.008	0.00054	0.00000
School [d]	0.00545	0.00000	0.184	0.00286	0.00000
University [d]	0.00061	0.00000	0.003	0.00051	0.00000
Outdoor [e]	0.00000	0.00000	0.000	0.00000	0.00000
			90th Percentile Building Average		
All	0.02383	0.00054	3.552	0.01298	0.00018
P&C [c]	0.00598	0.00033	1.721	0.00328	0.00000
Public [d]	0.00673	0.00044	0.727	0.00396	0.00000
Commercial [d]	0.00416	0.00027	1.989	0.00287	0.00000
School [d]	0.05227	0.00060	7.527	0.02474	0.00054
University [d]	0.01102	0.00000	1.106	0.00688	0.00000
Outdoor [e]	0.00324	0.00000	0.031	0.00294	0.00000
			Maximum Building Average		
Public	0.03477	0.00116	427.7	0.01213	0.00070
Commercial	0.02009	0.00304	145.0	0.01392	0.00280
School	1.50117	0.00233	142.8	0.65117	0.00185
University	0.11893	0.00298	47.02	0.05625	0.00298
			Mean Sample Concentration		
Public	0.00237	0.00008	4.937	0.00138	0.00004
Commercial	0.00161	0.00007	1.815	0.00109	0.00005
School	0.02707	0.00016	3.463	0.01264	0.00011
University	0.00501	0.00008	0.972	0.00265	0.00005
			Maximum Sample Concentration		
Public	0.17086	0.00469	2138.6	0.05127	0.00348
Commercial	0.09914	0.00569	724.8	0.06910	0.00569
School	3.01584	0.01167	694.6	1.30314	0.00639
University	0.46046	0.01044	233.0	0.23247	0.00510
Outdoor	0.19086	0.00471	546.3	0.17093	0.00387

[a] Asbestos having a length of at least 0.5 µm and at least 5 times the width (used in AHERA regulations to define when schools are sufficiently free of asbestos following abatement).

[b] Fibers at least 5 µm long and with a diameter of at least 0.25 µm (fibers projected to be counted by phase contrast microscopy).

[c] Combined Public and Commercial buildings. Based on building averages.

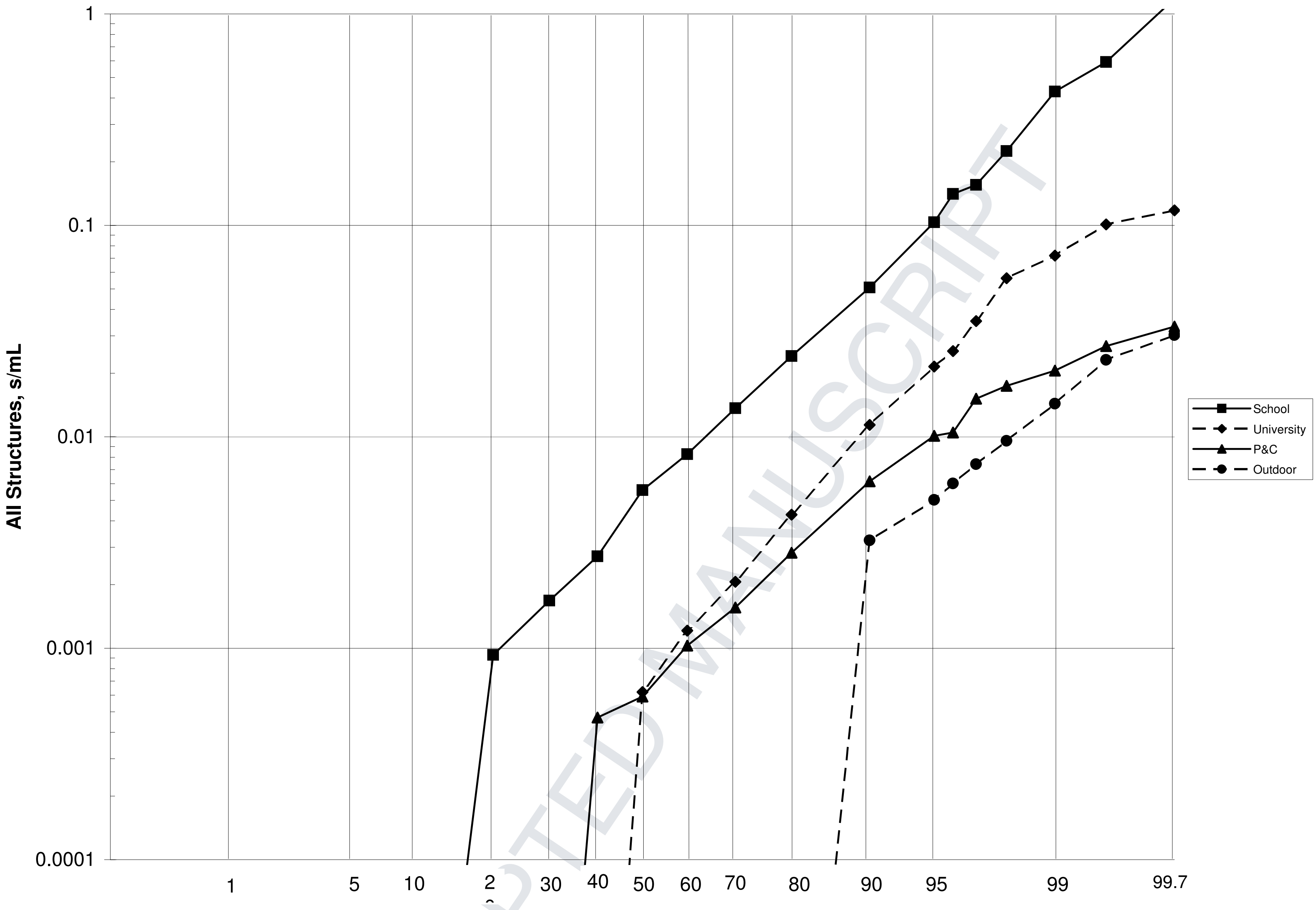
[d] Based on building averages.

[e] Based on individual samples.

TABLE 4

WIDTH AND LENGTH DISTRIBUTIONS OF ASBESTOS STRUCTURES, EXPRESSED AS A PERCENTAGE OF TOTAL STRUCTURES

	Width (µm)				
Length (µm)	<0.2	0.2 – 0.39	0.4 – 0.79	≥0.8	Total
		Chrysotile (13,107 structures)			
<0.5	45.08	0.02	0.02	0.00	45.12
0.5 – 0.99	38.16	0.22	0.02	0.01	38.41
1.0 – 1.99	11.06	0.88	0.08	0.00	12.02
2.0 – 4.99	2.24	0.69	0.35	0.07	3.35
5.0 – 9.99	0.29	0.18	0.14	0.11	0.72
≥ 10	0.09	0.08	0.11	0.09	0.38
Total	96.93	2.07	0.72	0.27	100.00
		Amphibole (363 structures)			
<0.5	5.23	0.00	0.00	0.00	5.23
0.5 – 0.99	23.69	4.68	0.00	0.00	28.37
1.0 – 1.99	12.95	15.43	2.75	0.00	31.13
2.0 – 4.99	2.75	8.26	10.47	3.86	25.34
5.0 – 9.99	0.28	2.20	2.48	2.48	7.44
≥ 10	0.00	0.55	0.55	1.38	2.48
Total	44.90	31.13	16.25	7.71	100.00


1
0.1
0.01
0.001
0.0001
All Structures, s/mL
1
5
10
2
30
40
50
60
70
80
90
95
99
99.7
School
University
P&C
Outdoor